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# Functional Hybrid Nano-Oxides

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This project was dedicated to investigate and engineer novel properties of oxide based materials, nanostructures and devices with properties that are not available in bulk materials. The proposal is based on common interest and complementary expertise of two co-PIs specializing in synthesis and transport (Schuller) and nanoscaled characterization (Shpyrko). We aimed to demonstrate tunability and control of these properties by incorporating oxides in devices with innovative architecture.

The extensive number of publications, in high impact journals and the large number of invited talks indicates that this is a very successful project, with a major impact on the field. This project is an important ingredient in at least five PhD theses, had the participation of 3 postdoctoral fellows and (no cost) contribution from visitors.

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ABSTRACT

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EXECUTIVE SUMMARY

This project leverages funding from AFOSR through extensive collaboration with colleagues at UC San Diego, Germany, Colombia, France, Israel, Argonne National Labs and Stanford Linear Accelerator Lab. In many cases we developed and used novel and unique experimental facilities, which are not accessible to us in our labs. This project also benefits from the no-cost contribution of researchers that are spending extended periods of times at UCSD, as well as many of the National Lab staff and the use of major national facilities. Graduate students and postdoctoral fellows are intimately involved in every aspect of this research.

## I. ACCOMPLISHMENTS

We have done several unique experiments to investigate the origin of the voltage-induced metal-insulator transition in $VO_2$ and $V_2O_3$ nanodevices. We find, using tour-de-force, local, submicron thermometry and Low Temperature Scanning Electron Microscopy that the nucleation of the metal-insulator transition has a large thermal component. These measurements arose from independent measurements of hot spots in other types of oxides, which allowed development of the microscopy technique. We have used the structural phase transition of V oxide to induce large changes in the properties of magnetic materials. We have incorporated V oxide into a spin device to investigate spin propagation across interfaces and address an important outstanding issue in the field regarding the effect of resistive mismatch on spin propagation. Frequency dependent impedance measurements have shown the presence of filaments across the metal-insulator transition.

We have made several major discoveries during the lifetime of this project. We found that the metal insulator transition in $VO_2$ can be induced by X-ray irradiation. This implies a very unique physical mechanism for the metal-insulator transition and it also opens up the possibility for the preparation of unique nanostructured materials. A second major discovery is the giant enhancement of the coercivity of thin magnetic films when they are in proximity to an oxide (such as $V_2O_3$), which undergoes a first order metal insulator transition. This is the first time that property transfer has been found between an oxide and a magnetic material. This is also may serve as the basis for a number of applications in the area of magnetic memory storage and energy conversion.

## II. PRACTICAL RESULTS

The results were summarized in a series of 13 papers in first-rate refereed journals, were part of 6 PhD theses, presented as invited and contributed talks at major meetings, and had a major influence on the education of graduate students and postdoctoral fellows.

This research has also been crucial in the education of several PhD students (Ilya Valmiansky, Mikhail Erekhinsky, Ali Basaran, Siming Wang, Sebastian Dietze, Elsa Abreu), providing important practical training and impacting their thesis work in many positive ways. Several postdoctoral fellows (Juan-Gabriel Ramirez, Thomas Saerbeck, Jose de la Venta) have contributed to the research outlined above. It is important to highlight that much of the research being done under this project benefits from extensive collaborations with chemist, physicists and engineers at UCSD and other institutions, thus the young investigators are exposed to an important modality of multidisciplinary, collaborative research.

This proposal has substantially contributed to the training and education of the new generation of the US scientific workforce: the UCSD graduate students and postdocs associated with this project that have finished their tenure, are currently employed in industry, national labs and academia. They are also developing independent research in related fields. Several of the young collaborators are in the middle of their PhD studies or postdoctoral fellowships, some of the work was finished during their spare time since the funding ended before.

Development of novel synthesis and characterization methods in area of Nano-Oxides paved the way to many on-going projects, such as ultrafast diffraction beamtime at the Linac Coherent Light Source (LCLS), worlds-first x-ray free electron laser facility, scheduled for Jan. 2016.

**Archival Publications (published 7/15, 2012 – July 14, 2015– project entirety)**


1. *Europium-Doped $TiO_2$ Hollow Nanoshells: Two-Photon Imaging of Cell Binding*, Sergio Sandoval, Jian Yang, Jesus G. Alfaro, Alexander Liberman, Milan Makale, Casey E. Chiang, Ivan K. Schuller, Andrew C. Kummel, and William C. Trogler, Chem. Mater. **24**, 4222 (2012).

2. *Role of Thermal Heating on the Voltage Induced Insulator-Metal Transition in $VO_2$*, A. Zimmers, L. Aigouy, M. Mortier, A. Sharoni, Siming Wang, K. G. West, J. G. Ramirez, and Ivan K. Schuller, Phys. Rev. Lett. **110**, 056601 (2013).

3. *Hot-Spot Formation in Stacks of Intrinsic Josephson Junctions in $Bi_2Sr_2CaCu_2O_8$*, B.

Gross, S. Guénon, J. Yuan, M. Y. Li, A. Ishii, R. G. Mints, T. Hatano, P.H. Wu, D. Koelle, H. B. Wang and R. Kleiner, Phys. Rev. B, **86**, 094524 (2012).

4. *Electrical Breakdown in a $V_2O_3$ Device at the Insulator-to-Metal Transition,* S. Guenon, S. Scharinger, Siming Wang, J. G. Ramirez, D. Koelle, R. Kleiner and Ivan K. Schuller, Europhys. Lett. **101**, 57003 (2013).
5. *Ultra-thin Filaments Revealed by the Dielectric Response Across the Metal-insulator Transition in $VO_2$*, J.-G. Ramírez, Rainer Schmidt, A. Sharoni, M. E. Gómez, Ivan K. Schuller, and Edgar J. Patiño, App. Phys. Lett. **102**, 063110 (2013).
6. *Spin Valve Effect Across the Metal-Insulator Transition in $V_2O_3$*, Mikhail Erekhinsky, J. de la Venta, and Ivan K. Schuller, J. Appl. Phys. **114**, 143901 (2013)
7. *Control of Magnetism Across Metal to Insulator Transitions*, J. de la Venta, Siming Wang, J.G. Ramirez, and Ivan K. Schuller, App. Phys. Lett. **102**, 122404 (2013).
8. *Coercivity Enhancement in $V_2O_3$/Ni Bilayers Driven by Nanoscale Phase Coexistence*, J. de la Venta, Siming Wang, T. Saerbeck, J. G. Ramirez, I. Valmianski, and Ivan K. Schuller, Appl. Phys. Lett. **104**, 062410 (2014).
9. *X-ray Induced Persistent Photoconductivity in Vanadium Dioxide*, S. H. Dietze, M. J. Marsh, Siming Wang, J.-G. Ramirez, Z.-H. Cai, J. R. Mohanty, Ivan K. Schuller, and O.G. Shpyrko, Phys. Rev. B. **90**, 165109 (2014).
10. *Coupling of Magnetism and Structural Phase Transitions by Interfacial Strain*, T. Saerbeck, J. de la Venta, S. Wang, J. G. Ramirez, M. Erekhinsky, I. Valmianski and Ivan K. Schuller, J. Mater. Res., **29**, 2353 (2014).
11. *Avalanches in Vanadium Sesquioxide Nanodevices*, Siming Wang, Juan Gabriel Ramirez, and Ivan K. Schuller, Phys. Rev. B 92, 085150(2015)
12. *Dynamic Conductivity Scaling in Photoexcited $V_2O_3$ Thin Films*, Elsa Abreu, Siming Wang, Juan Gabriel Ramirez, Mengkun Liu, Jingdi Zhang, Kun Geng, Ivan K. Schuller and Richard D. Averitt, Phys. Rev. B, **92**, 085130 (2015).
13. *Mesoscopic Magnetism and Superconductivity; Recent Perspectives*, Ali C. Basaran, Javier E. Villegas, J. S. Jiang, Axel Hoffman and Ivan K. Schuller, MRS Bulletin (in press 2015).

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